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# Frequency-duration analysis of composite distribution system using a non-sequential Monte Carlo simulation

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ABSTRACT

This paper presents a methodology for composite distribution system well being analysis based on non-sequential Monte Carlo simulation technique accounting uncertainties in capacity of distribution substation and distributed generation (DG). The method is based on a system state transition sampling approach which is used to calculate frequency and duration indices along with probabilities in healthy state, marginal state and risky state for a composite distribution system. Capacity of distribution substation and distributed generations are considered as normally distributed i.e. continuous capacity. The effectiveness of the method for evaluation of annual well being indices is demonstrated for a sample test system with DG capacity variation considering a seven step load model based on annual load duration curve. A comparative study is carried out which illustrates the effect of distributed generation capacity on well being indices of a distribution system.



## 1. Introduction

A power system consists of a generation, transmission and a distribution system. Traditionally, reliability analysis and evaluation techniques at the distribution level have been far less developed than at the generation level since distribution outages are more localized and less costly than generation or transmission level outages. However, analysis of customer outage data of utilities have shown that the largest individual contribution for unavailability of supply comes from distribution system failure [1].

Since distribution systems were designed to deliver electric energy to the consumer without any generation on these systems, hence adequate performance of the distribution system depends on substation capacity/power available. Due to many uncertainties present, including transmission capacity, generation availability, unplanned outages and other interruptions, the power available from transmission network via distribution substation to the distribution network is a random variable. It is natural choice from central limit theorem to assume the capacity available from substation as normally distributed.

Due to deregulation in electric markets, generating units of small size ranging from few KW to few MW synchronized at 11 kV bus in distribution system. These units are usually owned and controlled by customers known as distributed generation (DG). The locations of such DG are determined by customers and they are known to utility. However depending on the desire and needs of the customer DG will be turned on and turned off and thus contribute randomly to the substation capacity. So it involves uncertainty due to stochastic behavior of DG capacity. With recent advances in technology, there is an increasing amount of energy generated at local distribution level by independent non-utility generators such as renewable and combined heat power (CHP) schemes. Incorporating DG into the distribution system poses numerous challenges in terms of interconnection, protection coordination and voltage regulation. Increased system reliability and reduced cost are the primary incentives of adding DG to a power network. The other technical benefits [2] associated with the implementation of distributed generation includes in maintaining voltage profile, release of system capacity, energy loss reduction.

There is growing interest in combining deterministic considerations with probabilistic assessment in order to evaluate the "system well-being" also known as "health analysis" of electric power systems. This procedure evaluates the likelihood, not only of entering a complete failure state, but also the likelihood of being very close to trouble. The well being framework probably introduced by Billinton and Fotuhi-Firuzabad [3] incorporates the deterministic perspective with probabilistic approaches. This is described by a set of mutually exclusive, exhaustive operating states designated as healthy, marginal and risky as shown in Fig. 1 [4]. In the healthy state, there is sufficient margin to serve the total load demand. In

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**Nomenclature**

| | |
|---|---|
| $l_i$ | $i$th step load level of seven step load model (p.u.) |
| $T_{Li}$ | $i$th step load level duration (h) |
| $T_{LD}$ | total duration of study for load model (8760 h) |
| NLS | number of load levels of multi step load model |
| NDG | number of DG units |
| NG | number of generating units including substation and DG units |
| $G$ | system space |
| $S^{(K)}$ | system state |
| $q$ | total rate of transition (per year) |
| $p_j$ | probability of system state transition caused by departure of $j$th unit from its present state |
| $\lambda_h$, $\mu_h$ | failure rate and repair rate of $h$th unit of composite distribution system (per year) |
| $C_{S,k}$ | distribution substation capacity for $k$th system state (MW) |
| $f(C_{S,k})$ | probability density function for distribution substation capacity for $k$th system state |
| $\overline{C}_S, \sigma_S$ | mean and standard deviation of distribution substation capacity (MW) |
| $f(C_{dg,y})$ | probability density function for $y$th available DG unit capacity for $k$th system state |
| $\overline{C}_{dg,y}, \sigma_y$ | mean and standard deviation of $y$th available DG unit capacity (MW) |
| $C_{dg,y}$ | capacity sample of $y$th available DG unit (MW) |
| $C_{d,k}$ | total capacity available from DG units for $k$th system state (MW) |
| $C_{T,k}$ | total capacity available for $k$th system state (MW) |
| $T_k$ | state duration of $k$th system state (h) |
| $u$, $u'$ | uniformly distributed random digit between [0,1] |
| $\hat{p}_{Hi}, \hat{p}_{Mi}, \hat{p}_{Ri}$ | probability estimates in healthy, marginal and risky state for $i$th load level |
| $T_{Hi}$, $T_{Mi}$, $T_{Ri}$ | total duration in healthy, marginal and risky state for $i$th load level (h) |
| $T_D$ | total duration of all states (h) |
| $\beta$ | coefficient of variation |
| $\hat{\lambda}_{HM,i}, \hat{\lambda}_{HR,i}$ | transition rate from healthy state to marginal and risky state for $i$th load level (per year) |
| $\hat{\lambda}_{MH,i}, \hat{\lambda}_{MR,i}$ | transition rate from marginal state to healthy and risky state for $i$th load level (per year) |
| $\hat{\lambda}_{RH,i}, \hat{\lambda}_{RM,i}$ | transition rate from risky state to healthy and marginal state for $i$th load level (per year) |
| $n_{HM,i}$, $n_{HR,i}$ | number of transitions from healthy state to marginal and risky state for $i$th load level (per year) |
| $n_{MH,i}$, $n_{MR,i}$ | number of transitions from marginal state to healthy and risky state for $i$th load level (per year) |
| $n_{RH,i}$, $n_{RM,i}$ | number of transitions from risky state to healthy and marginal state for $i$th load level (per year) |
| $\hat{f}_{Hi}, \hat{f}_{Mi}, \hat{f}_{Ri}$ | frequency of encountering the healthy, marginal and risky state for $i$th load level (per year) |
| $\widehat{MUT}_i, \widehat{MDT}_i$ | mean up time and mean down time of system for $i$th load level (h) |
| $\widehat{MMT}_i$ | mean marginal time of system for $i$th load level (h) |
| $\hat{p}_H, \hat{p}_M, \hat{p}_R$ | system average probability estimates on annual basis in healthy, marginal and risky state |
| $\hat{\lambda}_{HM}, \hat{\lambda}_{HR}$ | average transition rate from healthy state to marginal and risky state on annual basis for system (per year) |
| $\hat{\lambda}_{MH}, \hat{\lambda}_{MR}$ | average transition rate from marginal state to healthy and risky state on annual basis for system (per year) |
| $\hat{\lambda}_{RH}, \hat{\lambda}_{RM}$ | average transition rate from risky state to healthy and marginal state on annual basis for system (per year) |
| $\hat{f}_H, \hat{f}_M, \hat{f}_R$ | average value of frequency of encountering healthy, marginal and risky state on annual basis for system (per year) |
| $\widehat{MUT}, \widehat{MDT}$ | average values of mean up time and mean down time of system (h) |
| $\widehat{MMT}$ | system average mean marginal time (h) |
| $\hat{\lambda}_{H,MR}$ | total system transition rate from healthy to marginal and risky state (per year) |
| $\hat{\lambda}_{R,HM}$ | total system transition rate from risky to healthy and marginal state (per year) |
| $A_{sys}$ | average system availability in healthy state (h/year) |
| $MA_{sys}$ | average system availability in marginal state (h/year) |
| $U_{sys}$ | average system unavailability of the system (h/year) |

the marginal state, the system is still operating within limits, but there is no longer sufficient margin to satisfy the acceptable deterministic criterion, therefore the system is on the edge of being in trouble. In risky state, equipment or system constraints are violated and load may be curtailed. It provides system engineers and risk managers with a quantitative interpretation of the degree of system security in electric power system. The degree of system well-being can be quantified in terms of the probabilities and frequencies of the healthy and marginal states in addition to the traditional risk indices. So evaluation of adequacy indices such as probabilities in healthy, marginal and risky state, frequency and durations in three states are important indices for distribution system to take corrective actions for inadequate operation of system.

Wangdee and Billinton [5] presented bulk electric system well-being analysis using sequential Monte Carlo simulation. Amaral et al. [6] developed efficient method for composite power system well-being evaluation based on non-sequential Monte Carlo simulation.

The work in area of adequacy assessment for distribution system considering DG was probably introduced by Hegazy et al. [7]. A state duration sampling approach for adequacy assessment of composite distribution system was applied. Arya and Koshti [8] used safety index for planning distributed generation in a distribution system. Matos et al. [9] has investigated probabilistic evaluation of reserve requirements of generating systems with renewable power sources. Arya et al. [10] described a probabilistic approach for the adequacy assessment of a distribution system having distribution generator (DG) sets, which are owned and controlled by customers. Markov modeling has been employed to obtain capacity outage table for DG sets. Arya et al. [11] described an analytical methodology for reliability evaluation and enhancement of distribution system having distributed generation (DG). Standby mode of operation of DG has been considered for this purpose. Haghifama and Manbachi [12] assessed the consumer-utility reliability of Combined Heat and Power systems for an distribution network. Banerjee and Islam [13] developed a probabilistic

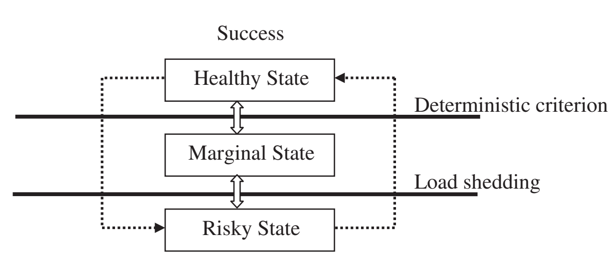


**Fig. 1.** State diagram for well being analysis.